The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

Next Generation Australian Community Climate and Earth-System Simulator (NG-ACCESS) – A Roadmap 2014-2019

Tom Keenan, Kamal Puri, Tony Hirst, Tim Pugh, Ben Evans, Martin Dix, Andy Pitman, Peter Craig, Rachel Law, Oscar Alves, Gary Dietachmayer, Peter Steinle and Helen Cleugh

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BACKGROUND

The Australian Community Climate and Earth-System Simulator (ACCESS) is a coupled climate and Earth system simulator being developed as a joint initiative of the Bureau of Meteorology (Bureau) and Commonwealth Scientific and Industrial Research Organisation (CSIRO) in cooperation with the university community in Australia.

Establishment phase objectives were to (i) enable the Bureau to realise modelling capability necessary to underpin the provision of its meteorological services; (ii) assist CSIRO to provide the best possible science for climate impacts and adaptation research and support its contribution to Fifth Assessment by the International Panel on Climate Change (IPCC); and (iii) in cooperation with the university community provide a world class modelling capability for the nation. A description of these activities is provided in the ACCESS Blueprint.[1]

These initial objectives are largely completed. In 2013, the Centre for Australian Weather and Climate Research (CAWCR) articulated the need for a Next Generation - ACCESS (NG-ACCESS) through the circulation of a consultation paper. It sought community views and guidance relating to the CAWCR view of the next phase of ACCESS development. Feedback reinforced the need for a generational change in ACCESS capability guided by the increasingly complex decision making needs of key stakeholders. A step change in model complexity supported by coordinated approaches to environmental modelling was considered necessary to address the scope of societal needs. Science supported by the utilisation of high performance computing infrastructure with enabling services were key elements. It was also clear that such science and infrastructure challenges were beyond the capacity of any one group. A paradigm change building on national and international intellectual expertise was necessary to realise NG-ACCESS.

The purpose of this CAWCR paper is to summarise the needs and drivers for building the NG-ACCESS, the achievements to date, provide a roadmap for the activities and propose a national governance model. This paper is not an implementation plan but is intended to provide the strategic intent of the Community in progressing NG-ACCESS.

ACKNOWLEDGMENTS

Contributions to this paper were coordinated through CAWCR. An initial draft was developed by Kamal Puri (Bureau), Tony Hirst (CSIRO), Tim Pugh (Bureau), Ben Evans (National Computational Infrastructure), Martin Dix (CSIRO), and from Christian Jakob and others at the Australian Research Council Centre of Excellence for Climate System Science (ARC CoECSS).

[1] http://www.cawcr.gov.au/news/pdf/blueprint_ACCESS20050630.pdf (new link required)

EXECUTIVE SUMMARY

Australia is vulnerable to weather and climate extremes, and faces serious risks from human-induced climate change. Our scientific knowledge has now advanced to the extent that we are increasingly able to model, and predict these phenomena on the time and space scales necessary to plan for their impact and develop responses. Providing such knowledge has benefit that will be realised through increasing national productivity, informing government, and enhancing the national well-being. Making optimum use of our national scientific skills to develop the best predictive and simulation tools are necessary to realise such knowledge and associated services. Australia cannot rely on overseas institutions alone to provide such capability given the unique nature of our climate and weather and for reasons of national security. These underlying issues resulted in the initiation of the Australian Community Climate and Earth-System Simulator (ACCESS) in 2005, under the leadership of the Bureau and CSIRO. This activity recognised that an Earth System Science (ESS) [2] approach was necessary to tackle the complex problems facing our nation.

This 2014-2019 Roadmap outlines a generational change in this initiative aimed at providing a more comprehensive state-of-the-science Earth System Model (ESM) capability that will meet the growing national needs. Through consideration of Australian vulnerabilities, sectorial needs and potential benefits, priority outcomes for NG-ACCESS are to provide timely and targeted information for:

- Improving public safety, reducing loss of life and aiding community resilience from natural hazards.
- Meeting the growing and complex challenges associated with climate change through informing national decisions related to mitigation, adaptation and shaping global solutions.
- Improving the management and sustainability of our environment assets.
- Enhancing national security and well-being, including the provision of sustainable and reliable energy, supporting people and community needs.
- Increasing national productivity, across the range of sectors impacted by weather and climate.

Substantial gaps exist to achieve these outcomes, and this NG-ACCESS Roadmap outlines requirements related to:

- An improved ability to predict site-specific atmospheric, terrestrial, marine and cryospheric conditions covering periods from hours to decades for weather and climate.

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[2] The term "Earth system science" (ESS) is used in a variety of ways in the scientific community, sometimes to indicate a broadening of the science from the traditional physical science (atmosphere, ocean, etc.), but on other occasions to refer to multi-disciplinary scientific endeavours. In this case ESS refers to the description and understanding of the complex interactions between the atmosphere, ocean, land, cryosphere, hydrosphere and biosphere, but also includes links to specifically human demographic and economic components.

- Improved characterisation of risk and uncertainty associated with model predictions.

- Enhanced and integrated modelling of the biogeochemical and physical processes and their interactions. Capabilities to predict the carbon, water, nitrogen and other chemical cycles are fundamental along with a priority to provide user relevant quantitative precipitation forecasting.

- Modelling focussed on the needs of climate change adaptation, mitigation and attribution at global and regional scales, considering extremes, tipping points and carbon flows.

- Process evaluation to verify and improve model representation of physical processes. Links with investment in national and international observational and associated science frameworks is crucial.

- Linking NG-ACCESS to human and economic system models to enable integrated assessments at global and regional scales i.e., understanding the coupled human-Earth system.

- The need to harness national and international scientific capability.

- Coordinated approaches to investment aligned with key national challenges.

The Roadmap describes nine impact areas and three associated infrastructure requirements. Enabling a "seamless approach" to decision making is an underlying paradigm. The scope of the activities is significant, encompassing more impact areas and science domains than originally envisaged under ACCESS. They include realisation of environmental prediction covering time periods ranging from hours, days, weeks, and extending out to seasonal and decades. NG-ACCESS provides a framework to bring together efforts related to weather forecasting, climate prediction, Earth System Modelling e.g., carbon flows, socio-economic or integrated assessment modelling, as well as ocean and coastal modelling.

In each area, science and infrastructure questions are posed to provide underlying alignment of the efforts necessary to realise NG-ACCESS.

The Roadmap outlines requirements, benefits with major work activities and deliverables for the short, medium and long term. An assessment of the relative priority of each component is provided based on state of the science, stakeholder needs and ability to impact decision making.

The Roadmap emphasises growing ongoing national and international coordination to realise “seamless prediction”. A multi institutional national program is proposed that can return an effective value proposition from community involvement. Community agreement on strategy, a shared vision, effective coordination and enabling infrastructure are central to the approach proposed.

The Roadmap proposes a new national level governance model to support the development and ongoing use of NG-ACCESS. It includes a high level National Advisory Committee representing key national players to provide guidance on strategic direction, priorities and alignment of investment. A Science Advisory Team and a Technical Infrastructure Team are proposed to guide the overall implementation with a National NG-ACCESS Project Leader responsible for the development and execution of work plans. Capability teams, sourced from national and international agencies realising the necessary skills will be developed to achieve agreed deliverables. An implementation plan with associated funding is the next step.

Hence, the Roadmap proposes a common vision, and approach sourcing the expertise and resources necessary to realise NG-ACCESS for the benefit of the nation. With the underlying complexity of the problems and the potential impact, such national level approaches are deemed absolutely essential.

1. INTRODUCTION

Australian communities, the economy, and the natural environment have demonstrated significant vulnerability to weather and climate. The annual sensitivity has been estimated to be near 5% of GDP or over AUD65B. Health, emergency management, defence, water security, energy, agriculture, mining, and coastal communities all represent domains with particular and significant residual vulnerabilities. Recent high impact weather manifested through the Black Saturday bushfire event of 7 February 2009, the "millennium" drought of 1998/2009, the Eastern Australian floods during the summer of 2010/11, Tropical Cyclone Yasi in February 2011 and the major flooding and bushfire events of 2013 highlight the multiple impacts and the effect on the triple bottom line of the nation.

Australia has suffered such events in the past. However, a link to climate change is emerging with evidence of associated impacts across the nation. Climate projections highlight more weather extremes, increased pressure on water security, and vulnerability in key sectors such as the agricultural sector. Demographic changes such as an ageing and urbanised population increasingly located on the coastal fringe place additional dimensions to the problems and compound the pressures faced by society and government.

Informed decision making is a key to adapting and mitigating these environmental impacts. However, such decision making typically considers a range of times and space scales and interdependent hazards. Very short lead times are often important in emergency response but for planning and major infrastructure decisions time scales extend to years and decades.

Following best international practice, it is now accepted that a multidiscipline ESS approach provides the knowledge, understanding and information to tackle the complex needs of government, industry and the community. Wide ranging and interdependent issues can be tackled systematically in the one framework to inform long term environmental and economic planning, as well as the more operational and tactical issues involved in immediate disaster reduction.

To this end, a Roadmap for a next generation national Earth system simulator is proposed for Australia. This will provide government and the Australian community with consistent high quality forecasts and projections required to address decision making on time scales from hours, weeks, months and decades. This approach builds on accomplishments achieved to date with the ACCESS modelling framework and associated government infrastructure investment.

The Roadmap for 2014-2019 summarises the rationale, strategic policy alignment, anticipated impacts, including national outcomes and outputs, science, resource requirements, an associated organisational and governance structure required to marshal national capability.

2. WHAT IS ACCESS AND WHAT HAS BEEN ACHIEVED?

Early in 2005, the Bureau and CSIRO made a major decision to jointly develop ACCESS to provide new world class modelling infrastructure to meet the complex and demanding challenges supporting meteorological service provision, and the science underpinning climate impacts and adaptation research. ACCESS was to model the major physical components of the Earth system with primary targets related to a coupled climate model to meet timelines for the IPCC 5th Assessment Report [3] (IPCC AR5), and new numerical weather prediction system to support Bureau operational needs.

Significant achievements were realised:

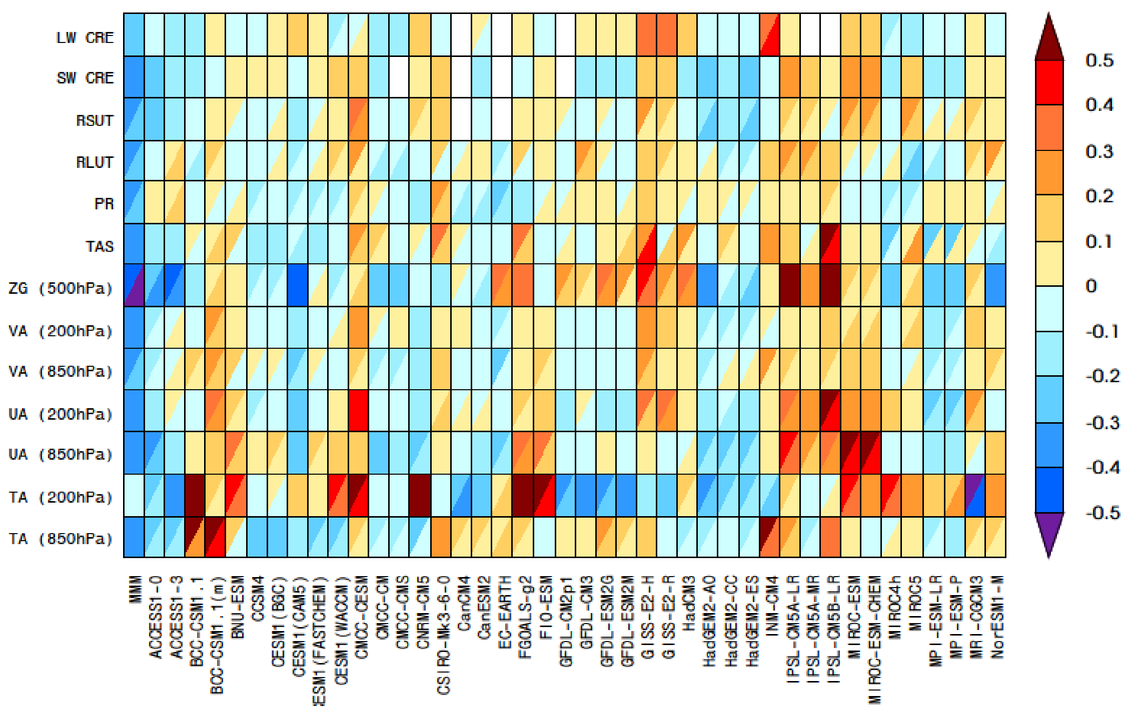

Fig. 1 (a)

[3] See http://www.ipcc.ch/report/ar5/index.shtml

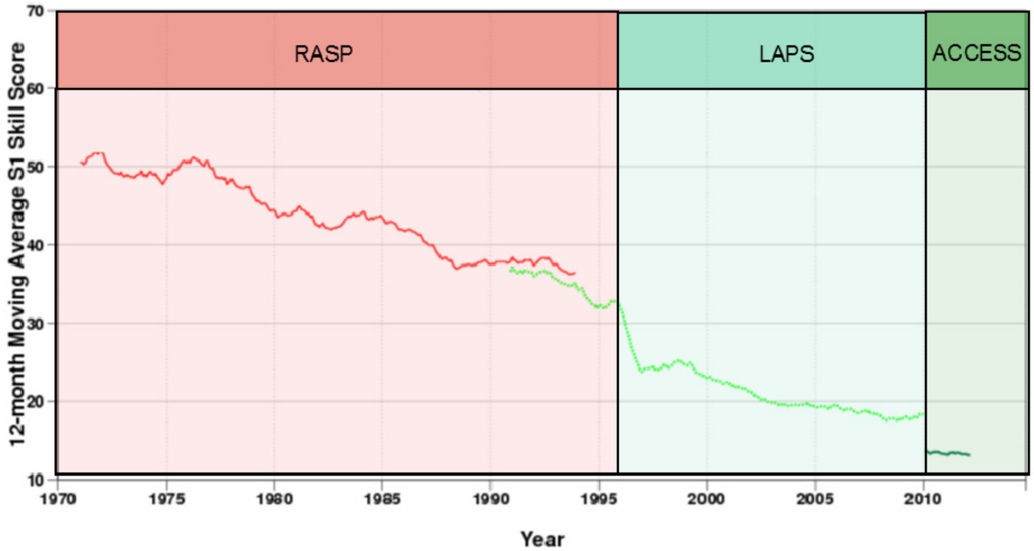

Fig. 1 (b)

Fig. 1 Evaluation of ACCESS modelling infrastructure (a) Relative global error of CMIP5 models (1980-2005) for 13 model fields. Blue indicates smaller error (i.e., better). ACCESS climate change simulations rank in the upper level of international models evaluated under the CMIP5 (b) Skill improve (lower is better) of NG-ACCESS model compared with previous Bureau models (RASP and LAPS).

- Centennial-length simulations from the coupled model version of ACCESS were submitted to studies associated with the IPCC AR5. In a range of model evaluation studies[4] shown in Fig.1a, ACCESS simulations ranked in the upper level of international climate models.

- A step change in our ability to forecast weather at the Bureau [5] was achieved by the ACCESS introduction in 2010 (see Fig. 1b). ACCESS is now informing decisions made by Government and the community e.g., guidance to weather forecasters and hydrologists during many extreme events e.g., the floods of 2010-11.

ACCESS is now being run nationally on supercomputers located at both the Bureau and National Computational Infrastructure (NCI). Through such activities as the Climate and Weather Science Virtual Laboratory, developed by the Bureau, CSIRO, NCI with support from the National eResearch Collaboration Tools and Resources (NeCTAR) Project [6] steps are being taken to further support ACCESS. These activities enable scientists to simulate and analyse climate and weather phenomena and establish a readily available archive of climate and weather data.

[4] IPCC WG1 Chapter 9 Evaluation of Climate Models see http://www.climatechange2013.org/images/report/WG1AR5_Chapter09_FINAL.pdf
[5] Puri et al. (2013), Aust. Met. Oceanog. J., 63, 265-284.
[6] See http://www.nectar.org.au/

This development was supported nationally by the Australian Government, the Australian Research Council (ARC), and through significant international collaborations. Infrastructure and atmospheric model development is being done in partnership with the UK Met Office and Korean Meteorological Administration (KMA). The United States of America (USA) National Oceanic Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory is also a key partner in the ocean model component. These approaches enhance the overall value proposition and are recognition that sharing of development is now necessary to deliver such complex science.

3. GOALS AND OUTCOMES

Goals are:

- To develop a next generation world-class national Earth System Modelling (ESM) system that will provide the predictive framework to support local, regional and globally informed economic, environmental and societal decision making.
- To reduce societal exposure to environmental multi-hazards by enabling a step change in the delivery of robust and relevant information characterising risk and associated impacts.
- To enable environmental forecasting and prediction on time-scales from hours to decades and at space scales unavailable through current Australian systems.
- To make NG-ACCESS the primary national modelling system attracting national investment and utilisation.
- To facilitate new science leading to improved understanding of high impact weather [7], climate variability and climate change through use of NG-ACCESS.
- To effectively utilise national and international intellectual capital in the realisation of a national ESM capability.

The key outcomes will be:

(i) Robust environmental information aligned with stakeholder and decision maker needs.

(ii) A nation better prepared to meet challenges relating to sustainability, resilience, environmental management, national security and social well-being related to weather and climate-related challenges.

(iii) Enhanced authority for the NG-ACCESS partners as a source of environmental and policy relevant information.

(iv) A national world class ESM capability, developed through the strategic national and international collaborations.

[7] Weather that has a major impact on one or more segment(s) of society

(v) Robust ESM infrastructure readily available to, and employed by, the Australian research community.

(vi) International recognition of Australia for its expertise in meeting global challenges such as high impact weather and climate change.

4. ESTABLISHING THE NEED

The unique environment and extent of the Australian Commonwealth present significant and inter related complex social, environmental and economic challenges. Factors exacerbating Australia's vulnerability include increasing urbanisation within the coastal fringe, a carbon dependent economy, income dependency on fossil fuel exports, marginal agricultural zones, stressed water and ecosystems, and vulnerability to flooding.

Sensitivity to Weather and Climate Variability

Sims [8] (2011) estimates the annual sensitivity of the Australian economy to weather and climate variability to be about five per cent of GDP (~AUD65B). Such vulnerability has been well recognised by the agricultural sector but it is clear from Fig.2, that weather and climate have a sizeable impact in other sectors of importance to Australia e.g., mining, services, manufacturing and finance.

Improved information related to weather and climate information has the potential to mitigate such national, sectorial and regional economic vulnerabilities.

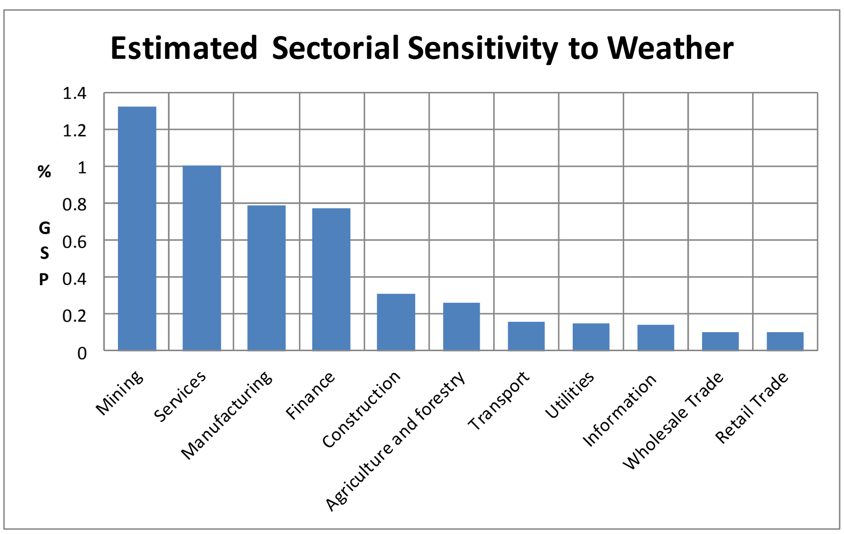

Fig. 2 Estimated sensitivity to Weather of Gross Sectorial Product in Australia. Based on adaptation of the US study undertaken by Lazo[9] et al (2011).

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[8] Sims, 2011: A Climate Forecasting Services Framework, Report to the Bureau of Meteorology,

[9] Lazo et al, 2011, Bull. Amer. Meteor. Soc., 92,, 709-720

Impact of Extremes and Natural Disasters

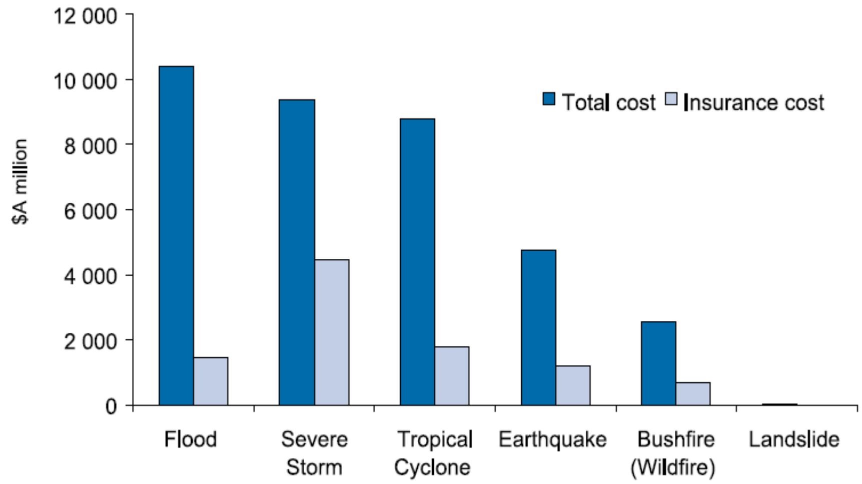

Fig. 3 Total and insurance costs by disaster type 1967-99. BTE analysis of Emergency Management Australia

Over the period 1967-1999, the cost to Australia from natural disasters was dominated by weather and flooding events, as shown in Fig. 3. Recent events further support these impacts:

- In 2010-11 the Queensland floods caused the death of 33 people and more than 78% of the state was declared a disaster zone. Over 2.5million people were impacted at a total cost estimated to be in excess of AUD5B[10] .

- Treasury estimates that the 2011 natural disasters resulted in a AUD9B reduction in production and reduced real GDP growth by 0.5%.

- CSIRO [11] estimates that the heat event of 2009 caused financial losses of AUD800M due to power outages, transport disruption and associated response. Such heat waves are “silent killers” especially for vulnerable and elderly.

NG-ACCESS can play a key role in the decision making processes by enabling informed decision making, through weather and short-term climate forecasting as summarised in APPENDIX A Boxes 1-3.

[10] Queensland Floods Commission of Inquiry (2012) see http://www.floodcommission.qld.gov.au/__data/assets/pdf_file/0007/11698/QFCI-Final-Report-March-

[11] CSIRO Climate Change Solutions for Australia (2011) see http://www.csiro.au/Outcomes/Climate/Climate-Change-Book.aspx

Climate Change

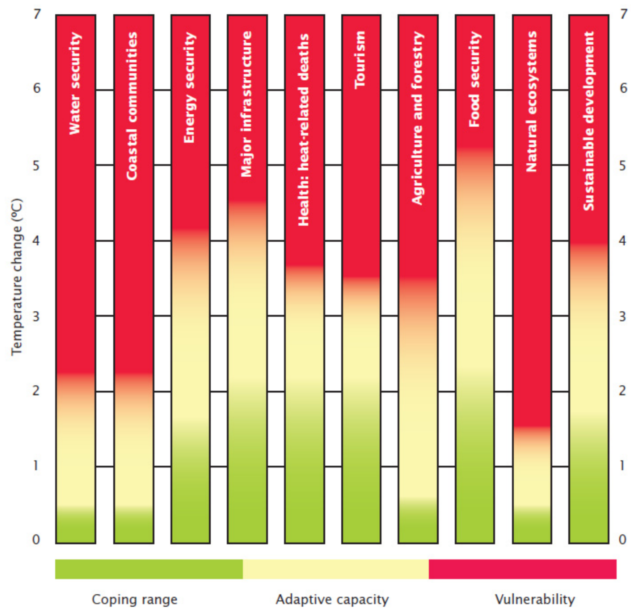

Fig. 4 Aggregated relative sectoral vulnerability to climate change in Australia and New Zealand, for a range of future climate scenarios. From IPCC 4th Assessment Report.

Australia to 2050: future challenges[12] highlights climate change as the largest threat to our environment and one of the most significant challenges to economic stability. Risks from anthropogenic induced climate change are articulated in the IPCC 4th Assessment Report[13] , A Plan for Implementing Climate Change Science in Australia (PICCSA)[14] , and the Garnaut Review[15] . As highlighted in Fig.4 sectorial vulnerability varies but for most sectors it is clear that the realisation of a temperature rise of 4°C will have significant consequences. With anthropogenic emissions now tracking near the worst case presented by the IPCC, the Climate Change Convention objective of a 2°C limit in global warming now seems increasingly difficult to attain. A 4°C warmer globe appears increasingly likely.

Additional indirect risks and impacts are also evident and the requirements poorly understood e.g., the demand placed on emergency response, impact on property, transport, financial services, potential changes to exports. These risks are articulated by the World Energy Outlook 2013[16] , The Climate Institute (2012)[17] , Global Risks 2012 [18] and through the World Bank (2012) Turn Down the heat[19] .

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12 http://archive.treasury.gov.au/igr/igr2010/Overview/pdf/IGR_2010_Overview.pdf
13 http://www.ipcc.ch/publications_and_data/ar4/wg3/en/contents.html
14 http://www.climatechange.gov.au/sites/climatechange/files/documents/03_2013/national-framework-climate-change-science.pdf
15 http://www.garnautreview.org.au/update-2011/garnaut-review-2011.html
16 http://www.worldenergyoutlook.org/publications/weo-2013/
17 http://www.climateinstitute.org.au/verve/_resources/TCI_ComingReadyorNot_ClimateRiskstoInfrastructure_October2012.pdf

Examples of particular Australian sectorial impact are discussed in APPENDIX A Case Study 4.

Informing Government

The recent impact of national scale disasters related to weather and climate have reinforced the need for responses that include high level coordination, a shared responsibility across society, knowledge informing an understanding of vulnerability and risks and a preparedness that enables local level response. The National Emergency Management Council (NEMC) has been tasked by the Council of Australian Governments (COAG) to coordinate a National Strategy for Disaster Resilience[20] . Common messages emerge through the Australian Critical Infrastructure Resilience Strategy[21] .

At climate timescales, the National Climate Change Adaptation Framework[22] ; PICCSA, the Energy White Paper (2012)[23] , Special Report Issue 49 - Heavy Weather: Climate and the Australian Defence Force[24] , and the Statement of Australian Government Requirements for Environmental Information[25] all consider the challenges of climate change from different perspectives.

To tackle these problems by reducing Australian emissions to five per cent below 2000 levels by 2020 The Emissions Reduction Fund[26] is now proposed as part of the Direct Action Plan.

The 2012 National Research Investment Plan[27] also highlights the need for the Nation to undertake strategic research investment to improve the national wellbeing and productivity. It advocates a national research fabric, involving coordination of research investment, investment principles and strategic research priorities. The key research challenges include the environment, resources, security, health, food, energy all with impacts climate change and extreme weather highlighted.

It is clear that implications and knowledge requirements surrounding climate change are a major consideration for government.

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[18] http://www.weforum.org/reports/global-risks-2012-seventh-edition

[19] http://www.worldbank.org/content/dam/Worldbank/document/Full_Report_Vol_2_Turn_Down_The_Heat_%20Climate_Extremes_Regional_Impacts_Case_for_Resilience_Print%20version_FINAL.pdf

[20] http://www.em.gov.au/Publications/Program%20publications/Pages/NationalStrategyforDisasterResilience.aspx

[21] http://www.tisn.gov.au/Documents/Australian+Government+s+Critical+Infrastructure+Resilience+Strategy.pdf

[22] http://www.climatechange.gov.au/sites/climatechange/files/documents/03_2013/nccaf.pdf

[23] http://www.aip.com.au/pdf/Energy_%20White_Paper_2012.pdf

[24] http://www.aspi.org.au/publications/publication_details.aspx?ContentID=354&pubtype=10

[25] http://www.bom.gov.au/environment/Statement_AGREI_web.pdf

[26] http://www.environment.gov.au/topics/cleaner-environment/clean-air/emissions-reduction-fund

[27] http://www.innovation.gov.au/research/Documents/NationalResearchInvestmentPlan.pdf

To meet such environmental challenges accurate and longer term predictions of hazards or "environmental intelligence' are articulated by the Bureau of Meteorology[28] to keep the nation safe and prosperous. Improved characterisation of long and short term risks based on knowledge and prediction of multi-hazards is a key component of the approach. CSIRO[29] has also responded by building capacity in their Flagships to deliver integrated solutions to the complex problems involving climate change

A key element of NG-ACCESS is improving our modelling to better understanding and characterise associated uncertainties relating to the climate system, on both short (seasonal) and long term (century) time scales.

In all these activities research services and operational delivery of climate and warning information is paramount to have impact. This requires strong links between the research, academic and operational agencies to realise the capacity and reliability to meet community expectations.

In summary key themes articulated by Government and the role of NG-ACCESS relate to:

- Improving public safety, reducing loss of life and aiding community resilience from natural hazards. Vulnerability and risks associated with weather and climate necessitate predictive capability, with unprecedented detail (including uncertainty) covering an increasing range of time and space scales.

- Meeting the growing and complex challenges associated with climate change through informing national decisions related to mitigation, adaptation and shaping global solutions. Development of NG-ACCESS as a world class climate modelling capability is already being supported to provide such information needs.

- Improving the management and sustainability of our environment assets. Concerns relate to marine and coastal resources, rivers, wet-lands, vegetation, ecosystems, soils, air quality, water quality and use, carbon and greenhouse emissions. NG-ACCESS provides the multidiscipline framework to address the complex interactions that are inherent in these problems.

- Enhancing national security and well-being, including the provision of sustainable and reliable energy, supporting people and community needs. Weather, ocean and environmental information relevant to defence, national security and renewable energy is already underpinned by ACCESS and will be extended. Coupling such climate models under NG-ACCESS with socio-economic models provides considerable insight into the long term nature of such challenges including those associated with trade, energy and food security etc.

- Increasing national productivity, across the range of sectors impacted by weather and climate. Predicting the sectoral specific impact of weather and climate employing more

[28] Bureau of Meteorology, Strategic Plan 2010-2015 see http://www.bom.gov.au/info/leaflets/strategic-plan-2010-15.pdf
[29] CSIRO Strategy 2011-2015 http://www.csiro.au/Portals/About-CSIRO/How-we-work/Strategy/CSIRO-Strategy-2011-2015.aspx

site specific details obtained through the NG-ACCESS will enable more effective productivity and sectoral adaptation and mitigation measures.

- Meeting specific international obligations of Australia in areas such as the Antarctic and climate change. The global nature of the NG-ACCESS modelling framework delivers considerable insight into both national and global impacts.

5. ALIGNING THE SCIENCE TO ENABLE SOLUTIONS

The International Council for Science (ICSU)[30], comprising non-government national science bodies and international scientific unions has considered what science is needed to address the societal needs outlined previously. The concept of Earth System Science has emerged with grand challenges around forecasting, observing, confining, responding and innovation. The "Future Earth: research for global sustainability" (2012)[31] advocates integration of weather, climate, ecosystem, energy, health, agriculture, engineering and social science research for near term (year-decade) and medium (20 year) term returns. Nationally, Gifford et al (2010)[32] considered the interdisciplinary "Science of the Whole Earth System" as necessary to achieve the desired societal outcomes.

Other esteemed bodies support these themes. For instance, America's Climate Choices: Panel on Advancing the Science of Climate Change produced by the National Academy of Sciences (2010)[33] highlights the need to integrate disciplinary and interdisciplinary research in an ESS approach. Research priorities are related to improved understanding, improved decision making, and feasibility of implementation.

The World Climate Research Program[34] (WCRP) has as its mission *to facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society*. The WCRP has defined six "grand challenges" which describe the major barriers preventing progress in critical areas of climate science and provides guidance for developing targeted research efforts. The research effort for each challenge fundamentally involves Earth system modelling on a range of time and space scales.

The IPCC also provides the international coordination to assess the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced climate change with climate models a key part of their approach.

The key science, infrastructure and relationship processes required to deliver outcomes against the goals are summarised in Fig.5.

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30 http://www.icsu.org/about-icsu/about-us
31 http://www.icsu.org/future-earth/media-centre/relevant_publications/future-earth-framework-document
32 http://www.science.org.au/sites/default/files/user-content/ess-report2010.pdf
33 http://www.nap.edu/catalog.php?record_id=12782
34 http://www.wcrp-climate.org/

Fig. 5 From goals to outcomes with NG ACCESS outcomes

A multidiscipline ESS is required but with linkages to national and international activities to increase the total available intellectual capital and enhance the value proposition.

6. SCOPE

It is also paramount that NG-ACCESS be linked to downstream activities that enable actionable and reliable information to be provided to sectors and interest groups that are vulnerable to weather, climate and associated extremes now and into the future. This implies links with organisations that can provide the necessary research and operational services.

The activities envisaged build on achievements to date and provide the NG-ACCESS Roadmap for the period 2014-2019.

The vision is that NG-ACCESS will become the national ESM of choice, employed across the Australian research community and by government in support of their mandated functions.

A core principle is to enable seamless prediction of the climate system on time scales ranging from weekly weather influences, to seasonal, and into the decadal and centennial periods. An enhanced NG-ACCESS, supported by ensemble [35] approaches, is essential to address this so-called seamless prediction paradigm, represented in Fig. 6. It is recognition that decisions are not made independently across domains encompassing a range of time and space scales. They are also being made in an environment of uncertainty. The step change in NG-ACCESS will be a framework comprising a common suite of models, employing common infrastructure that can deliver consistent information enabling user-specific decision making.

The probabilistic or ensemble approach is particularly relevant to the latter. NG-ACCESS will address the seamless prediction problem and achieve the desired objectives of a modelling system that is: (i) independent of horizontal resolution; (ii) semi-independent of Earth system components; (iii) having performance/behaviour that is understood across resolution/timescales; (iv) not tied to a specific systems e.g. a coupled climate model separate from the NWP suite; (v) utilising single code approaches as far as possible; (vi) flexibility in configuration e.g., not restricted to global model use only; (vii) can keep up to date with stakeholder requirements; and (viii) can incorporate the best science and technological developments as required.

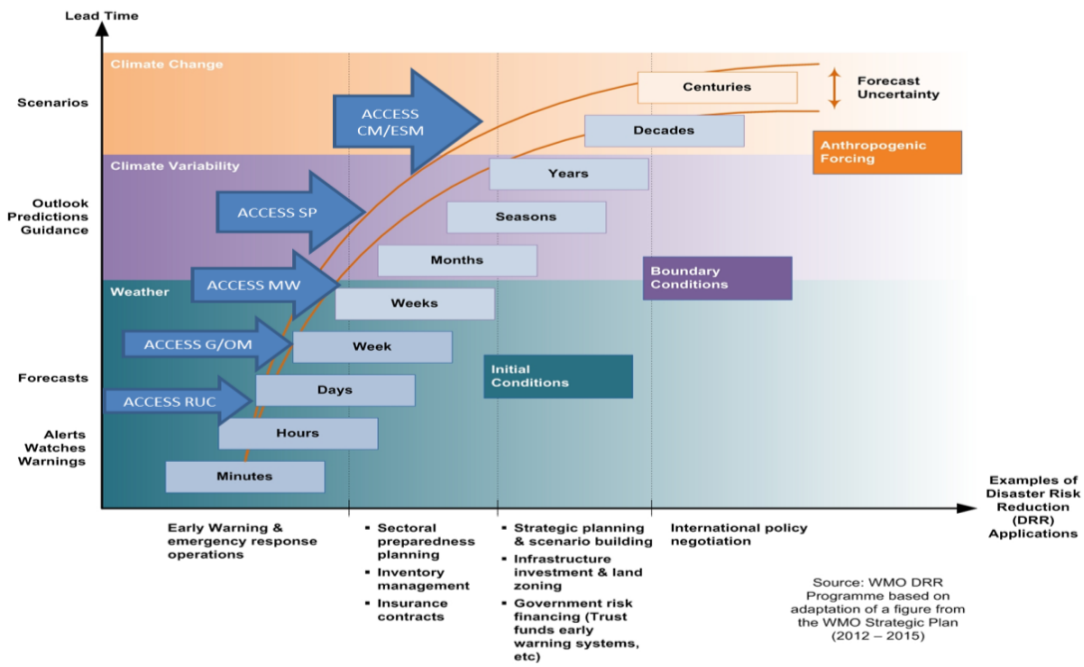

Fig. 6 Impact areas associated with a seamless forecasting system. Adapted from the WMO DRR Strategic Plan

(see http://www.wmo.int/pages/prog/drr/index_en.html#Seamless).

The approach is summarised in Fig.7, where the typical flow of recent developments in modelling and data utilisation at major international modelling is indicated. Key developments include:

[35] A technique in numerical prediction which enables an estimate of the uncertainty in weather or climate prediction as well as the most likely outcome. One model is run many times with variations in initial conditions, model physics etc.

- **Increasing model resolution**-to represent smaller scale forcing and high impact events which often occur at very small scales e.g., thunderstorms, tornadoes etc.

- **Increasing model complexity**-to enable the complex bio-geo-physical processes, and their interactions to be better represented and enhance the scope of model applications e.g., clouds, chemistry etc.

- **Improving key process representations**-to reduce forecast and projection uncertainty associated with representation of key processes in the models, such as clouds.

- **Increasing complexity in data assimilation**-to provide initial conditions and model balance for model predictions e.g., joint coupling of the ocean and atmosphere conditions for seasonal and climate prediction, non-linear and ensemble initialisation to handle the evolution of small scale and high impact weather.

- **Growth in satellite and in-situ observations, data volumes, variables/constituents being measured**-to provide data covering the full suite of ESM variables.

- **Continuing development and use of ensemble prediction systems**-to improve initial conditions and characterise uncertainty for decision making.

- **Rapid update and model on demand for high impact weather**-to provide high resolution rapidly updated forecasts (e.g. hourly) of high impact weather for use in the forecast decision making process.

- **Atmospheric, coastal and ocean models**-to provide detailed information on the atmosphere and marine environments.

- **Increases in skill performance** – in terms of predictive skill and in terms of skill in simulating observed behaviour.

- **Integrated Assessment Models**- to bring together models of society, climate and the economy at global and national scale. They provide policy-relevant information to aid climate mitigation and adaptation strategies and to explore scenarios of future development for Australia.

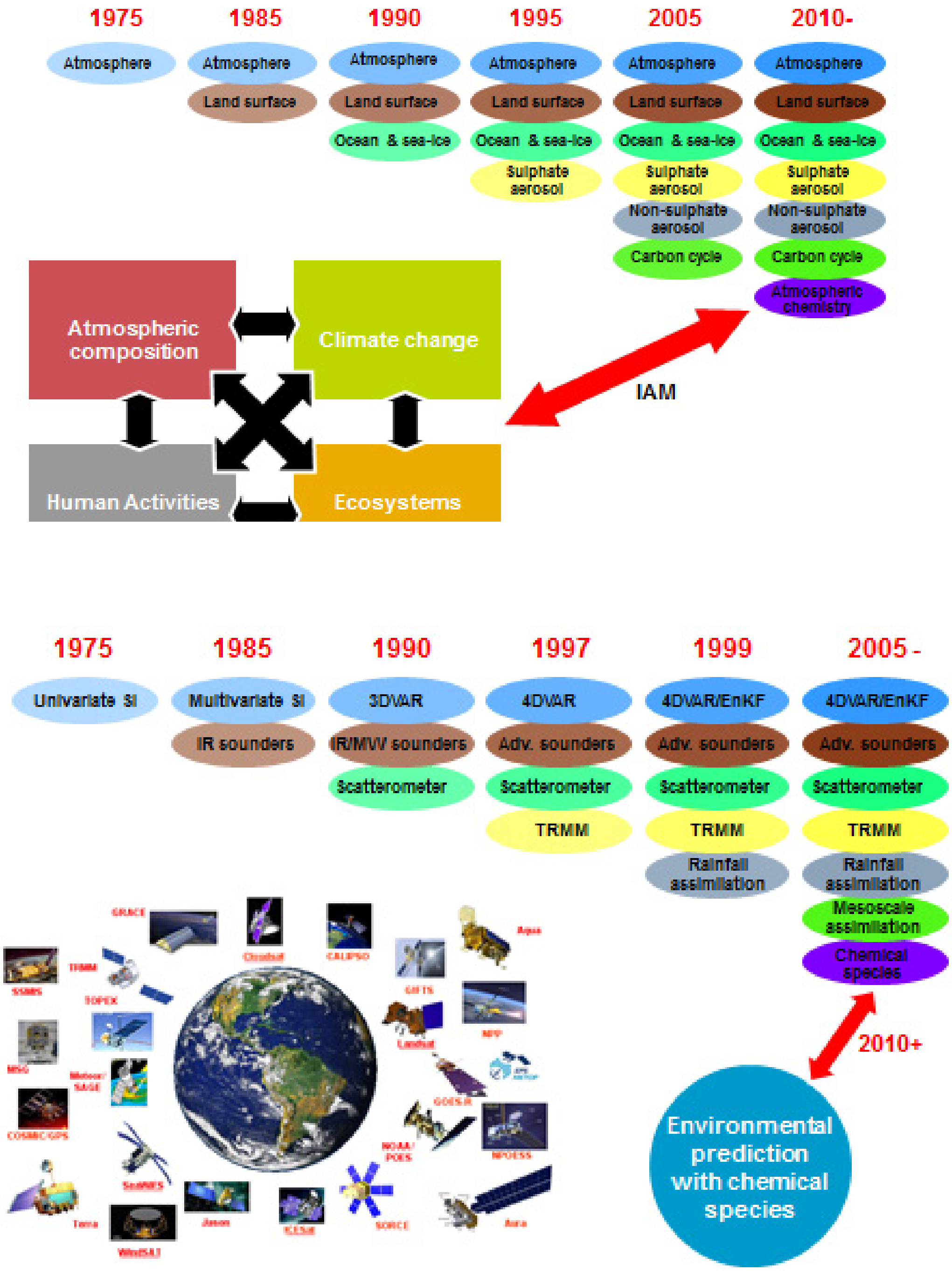

Fig. 7 Directions in modelling development and the use of satellite information.

The realisation of NG-ACCESS will be through the suite of component models summarised in more detail in Table 1. The ultimate aspiration is to share the same underlying science, code and infrastructure in their respective realisations. In this way, science gains relevant to shorter term weather forecasting or climate modelling can be directly reflected in all NG-ACCESS models.

Table 1 Proposed Main Components of the NG-ACCESS Model Suite

Timescale and Primary Purpose	Domain	System
Very Short-to-medium range (0-10 days)		
0-36h	City/Relocatable on Demand	ACCESS C/D*
0-24h Nowcasting-	Rapid Update Cycle	ACCESS –RUC*
0-240h	Global	ACCESS-G
0-144h	Regional	ACCESS-R
0-144h	Tropical Cyclone	ACCESS-TC
0-240h	Ocean Global/Regional	ACCESS-OM*
0-72h	Ocean-Coastal regional	ACCESS-CO*
Multiweek-to-seasonal		
Multiweek	Global	ACCESS-MW*
Seasonal	Global	ACCESS-SP*
Climate(Years to centuries)		
Atmosphere + Land Surface	Global	ACCESS-AM*
Atmosphere + Land Surface	Regional	ACCESS-RCM*
Ocean + Ice	Global/regional	ACCESS-OM
Coupled (atmosphere + Land surface + ocean)	Global	ACCESS-CM
Stand-alone Land surface	Global	CABLE
	Global Decadal Prediction	ACCESS-DP*
Earth System (Years to Centuries)		
	Global	ACCESS-ESM*
*Major New framework components developed under NG-ACCESS		
Upgraded framework components under NG-ACCESS		

It is clear a number of associated issues are involved in the end-to-end development and use of modelling infrastructure. Such issues include critical observational programs, e.g. earth observing capability, mechanisms for extracting and providing information, service provision, and integration of the ESM information into decision making processes.

The availability of ACCESS to researchers and other users, in a service-based framework is still emerging and required under NG-ACCESS before the community can directly use and benefit from the investments to date.

The Roadmap will now consider requirements related to:

- NG-ACCESS Framework Applications;
- Modelling infrastructure; and
- Building and using NG-ACCESS within the community.

7. APPLCATIONS AND REQUIREMENTS OF NG-ACCESS

Numerical weather prediction (NWP)

To meet national needs related to mitigating the impact of weather (as described previously), and especially that of severe weather and precipitation at local and national scales, timely, robust and user relevant information is required. Apart from the basic weather products there is considerable scope for application of high resolution NWP systems for downstream systems such as hydrology, transport, fire spread, and storm surge models, and for developing customised products for the insurance, agriculture, health, energy, and mining sectors.

To meet these needs, operational weather forecasting requires next generation capability including high resolution details (< 1 km), rapid model updates providing timely information hourly model repeats and characterisation of uncertainty.

The scientific basis of seamless predictions uses Ensemble Prediction Systems (EPS) across all forecast ranges with the consequence that forecast products are largely probabilistic. In addition, ensemble prediction by its very nature requires significant computational resources for both research and operational use.

A key future development will be in the domain of environmental prediction, including atmospheric composition and dynamics. Such a system combines all available remotely sensed and in-situ data to achieve global tropospheric and stratospheric monitoring of the composition and dynamics of the atmosphere from global to regional scales. Deliverables include current and the forecast air quality, three-dimensional distributions of key atmospheric constituents including: (a) greenhouse gases; (b) reactive gases; and c) aerosols.

Ocean prediction

Defence, search and rescue operations, hazardous chemical spill operations, offshore engineering, fisheries management and ocean observing have resulted in a growing demand for the prediction of the upper ocean state and circulation on time scales of days to weeks. Engineering design, the management of coasts, marine parks and fisheries represent additional needs. They require research and modelling capability related to physical oceanography, biogeochemistry and the coupling of the atmosphere-ocean. Demand for this work is expected to continue and extend into surf-zone and estuarine prediction, along with coupled physical and biophysical modelling.

The Ocean Forecasting Australian Model (OFAM) based on collaboration with the US Geophysical Fluid Dynamics Laboratory (GFDL) and their Modular Ocean Model (MOM) is the basis for large scale global and regional ocean modelling at high spatial resolution. A collaboration between the Royal Australian Navy, CSIRO and the Bureau called BLUElink has realised a forecasting system called OceanMAPS. These marine forecasting systems[36] have been implemented operationally and are providing daily forecasts and supporting the services. Future coupled development under BLUElink will be extended to include wave modelling nested within AUSWAVE[37].

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[36] See http://www.cawcr.gov.au/publications/technicalreports/CTR_052.pdf
[37] See http://www.bom.gov.au/nwp/doc/auswave/data.shtml

The long term aim in NWP is towards coupled modelling as the basis for global and regional weather forecasts, in a similar manner that is done for multi-week and seasonal forecasts. The NG-ACCESS framework should enable the gradual merging of the NWP and Ocean models, and operational suites towards coupled forecasting for NWP and ocean forecasting. In the long term this would provide a seamless approach from NWP to seasonal and multi-year timescales.

Synergy with NG-ACCESS has been achieved already through the adoption of common software in the coupled model versions of ACCESS. Future work requires focus on alignment in coupling approaches adopted in BLUElink and the NG-ACCESS coupled climate model.

Ocean model development will be aligned so that the relatively high resolution models developed for short-range forecast applications under BLUElink will subsequently, as computer power increases, become the next generation of ocean climate model and ultimately the basis for future versions of the ACCESS-CM coupled model. This will require consideration of the needs of climate modelling in the original configuration of BLUElink models.

The development of a suitable framework for coastal modeling needs to be explored further. The ocean modeling systems used for coastal domains is different to that used for BLUElink and climate. However, many features are similar and where possible code and infrastructure should be shared. Under NG-ACCESS a framework for interfacing coastal modeling with ACCESS needs to be developed. This framework needs to explore the modeling and infrastructure and how best to exploit the synergies between the two modeling systems.

The development of a suitable framework to meet these coastal needs is part of the activities considered within the NG-ACCESS Roadmap.

Multi-week and seasonal prediction

Multi-week and seasonal predictions fill the gap between shorter term “weather forecast” and “climate scale” projections. These predictions support preparedness, planning and decision making in a range of sectors such as water resource management, agriculture, emergency management, mining, natural resource management, finance, defence and tourism. The science of prediction in this domain has matured significantly with better understanding and monitoring of key influences e.g. the El Nino Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD) and the Southern Annular Mode along with the development of dynamical predictions systems that provide reliable and useful probabilistic regional climate predictions on these time scales.

The first generation Predictive Ocean Atmosphere Model for Australia, (POAMA)[38], is now running within the Bureau and providing products to the community. To realise the next generation capability and improved benefits, the inclusion of NG-ACCESS developments into POAMA is crucial.

[38] See http://www.bom.gov.au/climate/poama2.4/poama.shtml

Decadal Prediction and Climate Change Modelling

The PICCSA sets out a series of science challenges and capability required to address Australia's climate change policy. NG-ACCESS features explicitly or implicitly in many of these science and capability requirements. They include:

- Decadal prediction requires:
    - global coupled climate model, initialisation procedure and specified forcing changes
- Climate change projection at the regional scale requires:
    - global coupled climate model and specified forcing changes for changes in large scale drivers
    - regional climate model and specified forcing changes for resolving climate change at the finer spatial scales
- Projection of change in atmospheric greenhouse gas concentrations and natural emissions requires:
    - carbon-cycle model linked to the global coupled climate model and specified emissions changes
    - carbon-cycle model linked to the regional climate model for regional changes in sources and sinks.

With substantial decadal variability in, e.g., Australian rainfall, and in global mean surface temperature about long term trends, the public discourse is frequently dominated by discussion of decadal "trends". A state-of-science decadal prediction system including large-ensemble generation methodology would allow a compelling portrayal of the range of behaviours to be expected over the next decade, and how some of these behaviours may not necessarily align with long term trends.

Participation in model intercomparison projects (MIPs) and evaluation activities provides information necessary to guide model improvements and to quantify confidence in model outputs. This will be encouraged during NG-ACCESS. To date, there has been a focus by ACCESS on the Coupled Model Intercomparison Project (CMIP). The participation in CMIP will continue, but a range of other MIPs will also become relevant as the NG-ACCESS capabilities are expanded.

Impacts and adaptation analysis, and some aspects of fundamental climate science, require consideration of the range of potential climate outcomes and sensitivities. Current practice is to consider solutions from a broad set of models participating in CMIP in order to determine such ranges. NG-ACCESS, as a single model version, has important but limited applicability in such activities. The utility of NG-ACCESS would be enhanced if a perturbed parameter ensemble were developed, consisting of multiple model versions each differing significantly in their representation of the climate system. However, such development has significant scientific challenges. Nevertheless, such experimentation is part of the NG-ACCESS scope and will be pursued subject to available resources and opportunities.

There is extensive paleoclimate research activity, both observations and modelling, at Australian universities. Development for paleoclimate modelling, using standard CMIP configurations as a starting point, is in scope for NG-ACCESS, noting that this would generally be done in partnership between the universities and CAWCR. While some paleoclimate modelling applications may be done using standard CMIP model configurations, other applications require multiple thousands of years of integration. Often this is achieved through Earth System Models of Intermediate Complexity (EMIC)[39] that reduce the complexity in representation of physical process and operate at lower resolution. An NG-ACCESS EMIC is certainly relevant to such studies, ensemble based studies and to investigate aspects of climate variability.

Integrated assessment modelling

Future social, economic and environmental trends will place increasing demands for integration of climate change projections with trends in other global drivers to provide policy-relevant scenarios to decision-makers. There is a need to link ESM modelling to socio-economic models, recognising that the Australian Integrated Assessment Modelling (IAM) will further drive the need for quality and credible climate projections at regional scales.

The ACCESS Complex Systems Science team is already developing Global and National Integrated Assessment Models (GIAM and NIAM) based on simplified models of the physical system (climate, water, land) coupled to macro-economic and social dynamics models. As is the case for the physical model, to understand the economic and societal impact, an Australian capacity for IAM linked to NG-ACCESS remains important.

The direction of IAM development is dictated by demands from CSIRO's Integrated Carbon Pathways Program, by anticipated interaction with the IPCC process and by rapid current developments internationally and nationally in ESS.

Development will consider a series of levels of modelling activities that include:

- The large scale (i.e. global) IAM, GIAM, which currently uses a much simplified model of the physical climate system. A series of research questions arise in scaling down to national level to use in NIAM and in linking with downscaled water and land use models.

- There is a clear future path to using GIAM to provide dynamic anthropogenic land use change and emission information to NG-ACCESS in either inline or offline coupled mode.

- The development of integrated assessment models of intermediate complexity to assess the possibility of non-linear effects and tipping points in the coupled human-earth system is an important medium term (3 year) goal for the IAM team.

[39] https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch8s8-8-3.html

Model application in research and process evaluation

In addition to providing predictive tools, NG-ACCESS is envisaged to be a key community tool for scientific inquiry. Many of the phenomena of interest in the climate system cannot be observed comprehensively, and therefore understanding associated mechanisms and processes requires application of models. Key requirements for the NG-ACCESS for such research use are:

- Availability of a hierarchy of model configurations: The successful scientific use of NG-ACCESS will require the availability of a hierarchy of model configurations that can be employed as needed. The available configurations need to be well documented and made available to the wider community.

- Flexibility and Ease of use: Building a flexible and easy-to-use modeling system requires investment in its computational infrastructure (see section 8). Enabling an efficient exchange of ideas through the unification of the scientific computational environment (currently at NCI) is another important requirement for NG-ACCESS.

To improve predictions on many of the time scales of interest, there is a need to alleviate large and often long-standing model errors e.g., tropical mean and variability, Southern Ocean heat budget. Achieving this goal will require deploying existing resources in a more targeted way and increasing resources where a lack is identified. In particular, it will require building a critical mass of expertise residing in a variety of institutions into a targeted and well-supported effort. Only the combination of observational, model evaluation and model development approaches focussed on a particular problem will bring about the model improvements required to achieve improved predictions.

8. MODELLING INFRASTRUCTURE

The vision is to provide the leadership, resources, and expertise to establish and maintain a state-of-the-art high performance computational and simulation environment for use in addressing the most important and challenging problems in the Earth system sciences.

A robust simulation environment will be integrated into a broader, high-bandwidth information technology infrastructure and massive data archive, will serve as the enabling mechanism for the broad research community to achieve rapid progress in the Earth system modelling, computing, and related sciences. It will also provide for the education and training of future scientists.

This is a central part of the Roadmap and the need for a coherent infrastructure development and services programme within NG-ACCESS cannot be overemphasised. Past experience and examination of international practice indicates that a managed, robust, agile and comprehensive supporting infrastructure, delivers benefits to the scientific community and the enables the required societal outcomes.

Requirements for supporting infrastructure and services include:

- Hardware: internationally recognised computing and storage facilities;

- Software: practices that promote high performance and the efficient development of large simulation models, data intensive analysis and visualisation, and associated workflows and frameworks;

- Data: management practices, services and tools to manage and condense large data sets, extract and analyse information, and convey or represent these in a form suitable for scientific interpretation;

- Services: Approaches to provide programmatic access and user interfaces for science infrastructure to support a broad range of scientific tools, applications and services;

- Supporting Management: Augmentation of science teams with computer science, computational science, software engineering, user-interface design, web and data professionals to ensure a proper balance of skills; and

- Community Involvement: investigate, develop, adapt, and implement the infrastructure needed to support and facilitate effective communities and associated collaborations.

The development of the NG-ACCESS will take place in an environment of increasing model complexity and coupling, workflows and user-facing services, computational demands, and data volumes, all of which will drive major development decisions. There will be a need to improve the software management structures to be consistent across all models, maintain best practices in software engineering to improve software build management, provide user interfaces and reproducibility in model runs, develop workflow process, and improve data management. Systematic methods to test and verify software will enhance the national capability.

Further investments in software engineering staff for the code management, optimisation, software design, and test suites are required to provide greater sustainability and documentation of the NG-ACCESS modelling system. As an example, software scalability across a greater number of computer nodes and processor cores, especially for high resolution modelling will be required. Many-core processor and computing architectures utilising hybrid parallelism and new programming models are emerging today with moves towards an Exa-Scale computing platform within the next decade. This will increasingly place demands on NG-ACCESS.

It is also clear that the existing practices of separating model simulations, data, analysis, and visualisation are no longer practical due to the sheer volume of data produced and the time and effort required to move data continually from computational system to storage to user. Thus, it will be necessary to generate, store and process data in situ, in a highly integrated, and managed way through comprehensive infrastructure (supercomputer, data-intensive processors, and high-performance storage), which are interfaced to researchers and practitioners through parallel tools, data services, and virtual laboratories.

A detailed science infrastructure plan is needed taking into account the future software, data, services, and respective computational, storage and network resource needs of the entire NG-ACCESS community. To address these issues, NG-ACCESS will need collaborators focussed on the delivery of comprehensive and integrated, high-performance, computational and data-intensive infrastructure and services, as undertaken through CAWCR, BoM, CSIRO, NCI, the universities, and international programs. In parallel, it must also provide for, and support the development of, specialised skills necessary for leveraging the full value from the large infrastructure investments, and implementing tailored, user-facing services that will deliver on the goals of the Roadmap.

9. PROVIDING NG-ACCESS TO THE COMMUNITY

NG-ACCESS and its components are complex software systems and vast data collections that are envisaged to be used by a wide variety of NG-ACCESS partners and stakeholders for a variety of purposes. Hence, serving these data and systems to the wider community in a flexible and accessible form is of great importance.

User-facing services are required to improve discoverability, accessibility and ease-of-use to the NG-ACCESS software and data repositories, to hide infrastructure complexity and to deliver or enable discipline specific simulations and analytics, knowledge and visualisation applications. Additionally, tools and services to support the infrastructure development and management of projects, teams and communities are required for efficient communications and collaborations to deliver on the goals of the Roadmap.

The infrastructure services' goal is to support mainstream research capabilities in an ongoing and sustainable manner. The last few years have seen some significant progress in this area, mainly facilitated by enhancing existing efforts through new investments in the ARC CoECSS Computational Modelling Systems Team; the Fujitsu-NCI Collaboration to improve the application scalability and performance of ACCESS models; the Climate and Weather Science Virtual Laboratory, and in research data storage, petascale HPC and cloud computing infrastructure at NCI, funded from the Super Science Initiative[40] projects and supported by the major NCI partners.

The Climate and Weather Virtual Laboratory's goal is to enrich the scientist's access to resources, reduce technical barriers to using state of the art tools, facilitate the sharing of experiments and results, reduce the time to conduct scientific research studies, and to elevate the collaboration and contributions by the Australian research community to the development of the NG-ACCESS. Through the proposed integration and enhancements of existing community software such as NG-ACCESS software infrastructure, the laboratory will produce an integrated facility for climate and weather simulations and process studies.

For NG-ACCESS to make the transformative paradigm shift and become the indispensible community research service in weather and climate prediction, it is crucial to maintain support in this important area throughout its development. The realisation of this vision requires a national infrastructure program that can fund the entire purpose-designed environment as an integrated whole.

[40] http://education.gov.au/super-science-initiative

10. KEY SCIENCE AND INFRASTUCTURE QUESTIONS FOR IMPACT

The primary impact areas define high level questions related to science and infrastructure that need to be addressed for an effective program. They are summarised in Table 2. In some cases science questions have been posed in existing policy documents such as the PICCSA. In these cases those relevant to NG-ACCESS have been employed. In the other cases the science and infrastructure issues are based on an assessment of national and international science trends. They represent core issues that need to be addressed as part of this Roadmap.

A number of issues are relevant across the various components of the program e.g., initialisation of models through data assimilation, but have been separated because there are particular challenges relevant to the time scale and/or the applications. However the cross cutting nature of these capability issues requires a coordinated approach to their implementation.

It is also recognised that not all the science and infrastructure issues can be addressed within current funding. This will ultimately place a limit on possible achievements.

Table 2 Impact areas and associated NG-ACCESS capability components. Key science and infrastructure questions required for delivery of impact are indicated. Where appropriate links to the relevant PICCSA component (mitigation, adaptation and global solutions science) are given. Production of long term reanalyses suitable for climate purposes is also an output in many cases.

Benefit and Impact Areas	NG-ACCESS Suite Component(s)	NG-ACCESS Prediction Problem and Target Time Scale	Key science and infrastructure questions
Local scale emergency response to fire, floods, winds, surges, impacting personal safety, transport, damage, economic loss etc.	ACCESS C/TC/RUC	Nowcasting-Very Short Range Prediction (0-12h)	How can novel high resolution e.g., radar and satellite observations be used to initialise models and improve the skill in predicting non balanced convective scale processes? What improvements in predictive skill will be obtained through improved representation of convective scale physics? How can the reliability of high resolution ensemble-based very short term forecasts be increased? What changes to the model dynamical core and associated model infrastructure are required to meet current and future high resolution prediction requirements? What verification techniques are suitable for the evaluation of high resolution models?
Emergency management, operational planning, warnings of floods, health, chemistry, storms, water, agriculture, energy, transport etc.	ACCESS R/G/	Global, Regional Weather Prediction (0-10 days)	What improvements in predictive skill will result from higher resolution global and regional models that resolve mesoscale processes? What combination of data assimilation,

			modelling system and use of observations will improve the predictive skill and enable representation of uncertainty in forecasts? With improved resolution what improvements in the representation of clouds, radiation, convective processes, the land surface and planetary boundary layer schemes are required to enhance global scale model predictive skill, especially in relation to precipitation? What changes to numerical techniques and coding will be required to provide computational efficiency with models of increasing resolution and complexity? What is the impact of coupled atmosphere-ocean modelling on forecasting skill? What is the best way to provide robust modelling infrastructure for operational needs?
Operational planning relevant to defence, offshore and coastal industry; maritime spill and release prediction, maritime safety, port operations, search and rescue, sea ice, coastal and maritime environmental management.	ACCESS OM/CO	Prediction of global and coastal marine conditions (0-10 days)	What is the optimal data-assimilation scheme for ocean forecasts out to days? What is the role of surface waves in air-sea fluxes, and how important are they for ocean forecasting? Is weather-scale ocean-atmosphere coupling important and feasible for atmospheric and ocean forecasting on time scales of days? Are sea-ice predictions feasible on time scales of days? How robust are coastal hydrodynamic models downscaled from global predictions across all time scales and is two-way nesting important? What are the data sets and data-assimilation approaches that will enable truly predictive beach and shelf models on time scales of days? How can process-based shelf and beach models be extended to seasonal and longer time scales?
Emergency preparedness, water and agricultural management, fisheries, finance, energy Planning for management of agriculture, water, drought preparedness, tourism, emergency preparedness ,finance, market trading, re-insurance	ACCESS SP/MW	Intra seasonal prediction (1-4 weeks), Seasonal Prediction (0-12 months)	What approaches are required to bring ocean, land and atmosphere data assimilation together to advance the initialisation and representation of uncertainty in coupled seasonal and multiweek prediction models? What climate processes e.g., ENSO and their representation in models are critical to improving the predictability over the Australian region on weekly to seasonal time scale? What level of skill improvements will be achieved with increasing model resolution

			and model complexity? Can key hindrances associated with growth of model errors and biases be overcome to improve overall skill?
Carbon management and accounting, water resources management, environmental information, integrated assessment, climate	CABLE Land Surface and terrestrial biogeochemistry	Short term, seasonal and climate scales prediction	What is the role of natural land carbon sinks in sequestering emissions, and what will happen to these processes in the future? (PICCSA Mitigation) How can we use our natural land sinks and other terrestrial processes to mitigate Australian emissions? (PICCSA Mitigation)
Long term infrastructure, social, economic and security planning	ACCESS Decadal	Decadal Prediction (0-20y)	What are the ranges and probabilities of potential change in climate and extreme weather events during the next decades? (PICCSA Adaptation) What key processes must ACCESS include to simulate decadal climate modes correctly? Which climate variables have predictive skill on the decadal scale? What model initialisation methodologies give the highest predictive skill? How might the modelling system be utilised to effectively give uncertainty estimates for potential trends?
Long term infrastructure, social, economic and defence planning. Strategic environmental, water and energy planning. Contribution to global solutions (via IPCC and CMIP contributions)	ACCESS CM	Climate change projections (global/large scale drivers and regional) (decades to centuries)	What can past climate change in the Australian region tell us about the future? (PICCSA Adaptation What changes that we observe in the climate in the Australian region can be attributed to human influences? (PICCSA Adaptation) What are the potential changes in the large-scale climate drivers affecting the Australian region on time scales up to a century? (PICCSA Adaptation, Global solutions) What are the potential changes in climate and extreme weather events on the local to regional scale, suitable for adaptive decision making, on time scales of up to a century? (PICCSA Adaptation, Global solutions) What is the potential impact of climate change on the ice shelves and ice sheets of the Antarctic? (ACSSP Theme 1) What is the impact (both benefits and costs) of geoengineering options? (PICCSA Global solutions) How might the modelling system be utilised to effectively give uncertainty estimates for climate change trends? Can complex coupled phenomena be

			understood in physical terms through experimentation with a hierarchy of model configurations?
Long term strategic resource and environmental planning. Mitigation strategies. Contribution to global solutions.	ACCESS ESM	ESM – Carbon Cycle & Atmospheric Chemistry (decades to centuries)	How much greenhouse gas is being emitted by Australia and regionally (inverse modelling)? (PICCSA Mitigation) What will happen to the natural land and ocean carbon sinks in the future? (PICCSA Mitigation, Global solutions) What are the potential changes in the large-scale climate drivers affecting the Australian region on time scales up to a century? (PICCSA Adaptation) What is the impact (both benefits and costs) of geoengineering options? (PICCSA Global solutions)
Strategic regional, global, social, economic planning. Mitigation strategies. National security, socioeconomic and climate feedbacks Contribution to global solutions.	IAM	Integrated assessment modelling (decades-centuries), including linkage to ACCESS	What are the major climate/socio-economic feedbacks that may occur, at both the national and global scale, and what are their policy implications? (PICCSA Global solutions) Nationally, what is the optimal mix of mitigation and adaptation strategies based on specific decision criteria (e.g., economic, social, environmental)? How might IAM inform anthropogenic land use and emissions change to be used in ACCESS? What is the impact (both benefits and costs) of geoengineering options? (PICCSA Global solutions)
Infrastructure supporting ACCESS modelling and simulation	Modelling Systems	Modelling and simulation infrastructure	What modelling practices and software engineering are required across all models to support future modelling requirements? What further investments are required for code management, optimisation, software design and testing to provide robust modelling infrastructure meeting user needs? How can software be optimised across compute nodes and processor cores as we move to the exascale computing required to meet very high resolution modelling demands? How can national and international partnerships most effectively be leveraged to support ACCESS infrastructure?
ACCESS infrastructure services for the community	Virtual Laboratory	To manage ACCESS services and user support	What integrated modelling, and simulation services, model analysis services, community data portals and web-based services site are required to support the ACCESS research community?

			What facility interfaces, analytics and data libraries are required to support the management and analysis of Earth system data? Can the ACCESS specific services be linked to other community services involved in Erath system science?
Computing and Storage Resource Infrastructure	Enabling Resources	Supporting all ACCESS computational and data storage demands	What HPC infrastructure and network resources are required to support the ACCESS community (research and operational) now and into the future? How can the ACCESS community support the provision of the HPC requirements?

There have been considerable gains with weather forecasting with ACCESS. However the demands are considerable and higher resolution probabilistic based modelling is increasingly important to meet the challenges given time and space scales of high impact weather e.g., rapid updates of precipitation forecasts at the catchment scale to meet flood warning needs and associated multi-hazard information at the coastal interface. This does not mean that single state and probabilistic based solutions for global and regional forecasts are not needed. Indeed they are absolutely necessary to achieve high quality local forecasts matching stakeholder needs. Investment to realise stakeholder priorities remains an issue.

Secondly multi-week/seasonal predictions using POAMA have proven successful and developing this capability is considered a growing requirement by stakeholders to mitigate risk and optimise opportunity. To extend the predictive skill and specificity of POAMA, a transition to the NG-ACCESS framework is considered important.

In the ocean and coastal domain there is on-going pressure for a coastal modelling capability to provide necessary information to address environmental issues e.g., eReefs. It is not clear how to grow the resources for this capability. For ocean forecasting a base capability requirement remains.

To address climate change issues, there is a continuing need for NG-ACCESS capability to deliver world class information to meet mitigation and adaptation measures on time scales from years to decades as articulated by the Department of the Environment and such programs as the Regional National Resource Management Planning[41] for Climate Change. A capability to provide decadal scale predictions is highlighted based on the needs of long-term planning and management decisions, but the science is new and the utility of such predictions remains uncertain. Progression of this will depend on significant new resources.

A need for improved and higher resolution coupled modelling remains (targeting regional to urban scale, as part of a regional climate modelling capability), and exploratory work in these areas will be conducted during the period of the Roadmap. A carbon focus, based on CABLE and NG-ACCESS ESM is needed to deliver improved information about carbon emissions and the carbon budget (both regionally and globally). NG-ACCESS will provide input to climate information services and importantly help quantify uncertainty in the projections.

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[41] http://www.climatechange.gov.au/NRMfundstream2

IAM remains problematic and in a vulnerable state although the potential return informing social and economic consequences of climate change is significant. An increased level of investment is required for effective delivery of information.

The programs that provide the underlying support services, computing and storage resources are currently in reasonable shape for the short-medium term e.g., NeCTAR Virtual Laboratory. However its ability to deliver beyond 2014 is not known.

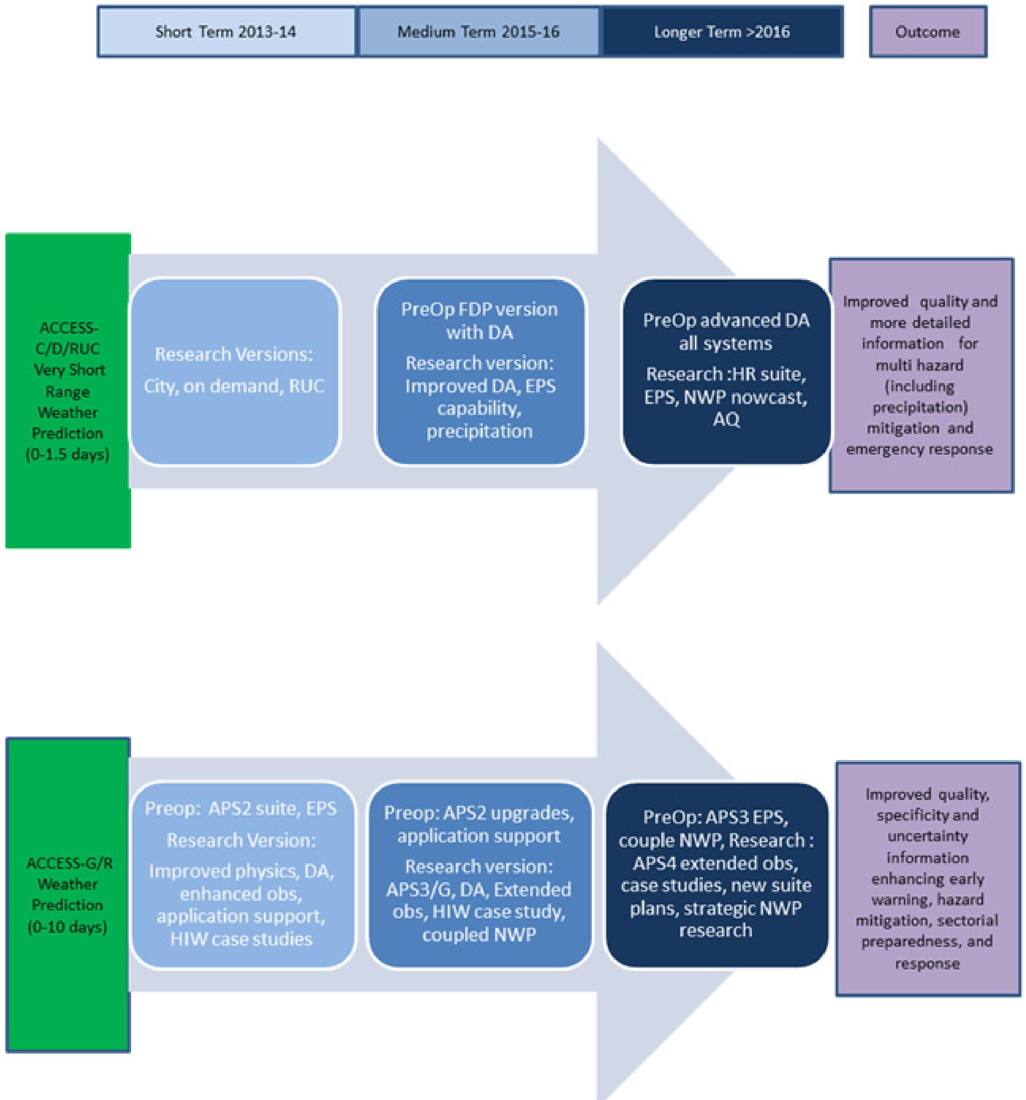
In the long term, significant resources will be required especially in next generation weather and climate models that will require exa-scale supercomputing. Significant model architecture work is required to exploit these supercomputers, as well as tools for the complex visualisation and analysis. These infrastructure support and community services issues are especially important at the later stages of the Roadmap but need to be planned for now.

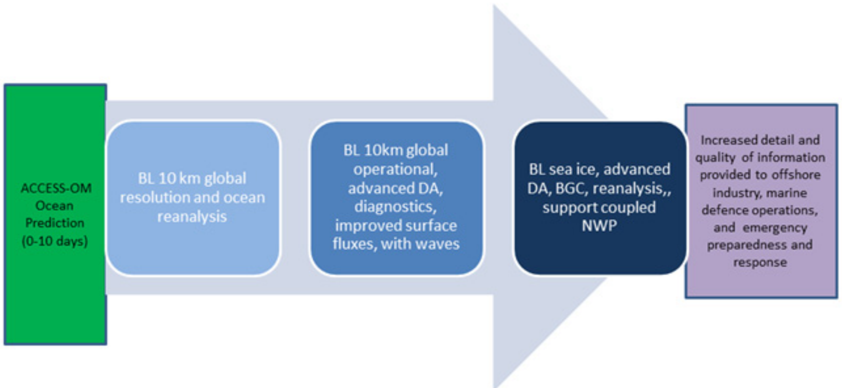
In summary, the list of impact areas is significant and has the potential to provide ongoing and enhanced national benefits. Assuming there is a nationally coordinated approach supported at existing levels of resources, some level of base capability will be provided to stakeholders. However, this capability will have limitations when compared to the wide ranging needs across the various sectors and time scales on which decisions are being made. National coordination is crucial but by itself not enough. Many of the current efforts are tenuous and to match stakeholder priorities it is clear additional and coordinated investment is required. Resources will influence the community's ability to provide the science to address stakeholder needs.

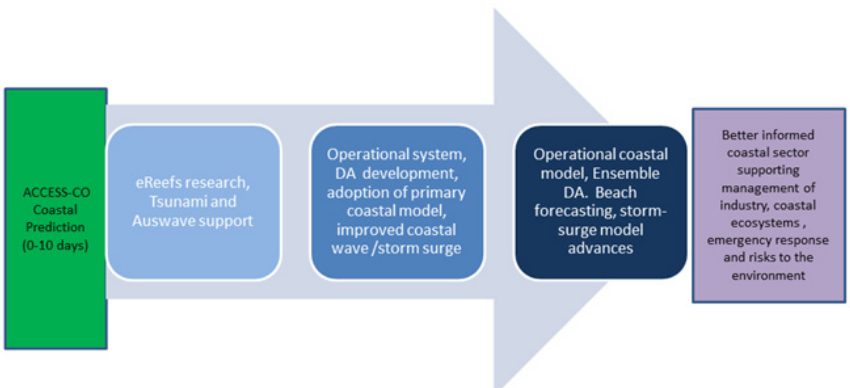
11. IMPLEMENTATION AND TIMELINE

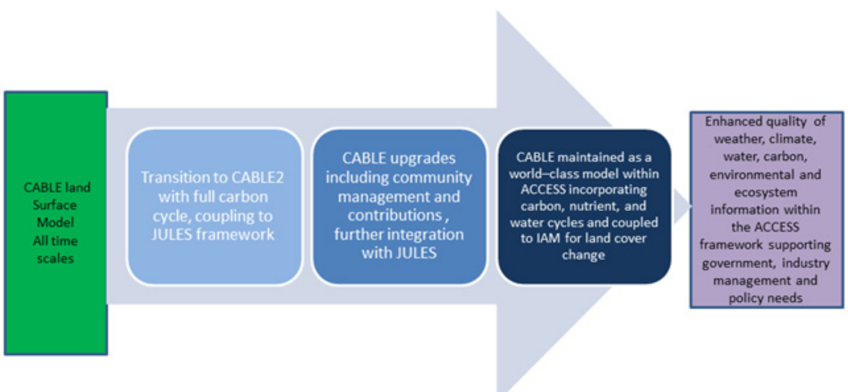
The evolution of NG-ACCESS Phase 2 activities across short, medium and long term time scales is shown in Fig. 8 for each framework component along with expected high level deliverables. The assessed impact at the end of the Roadmap period and CAWCR priorities for these activities are also provided. This is a high level summary and does not purport to represent all components of the activities that are in-scope and is subject to funding considerations.

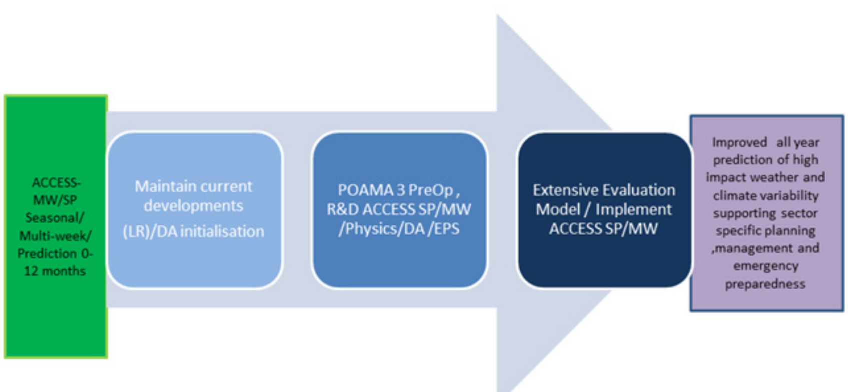
The scope is significant with many activities covering a large number of time scales impacting prediction of high impact weather associated with emergency response, to meeting the planning and policy related to climate change.

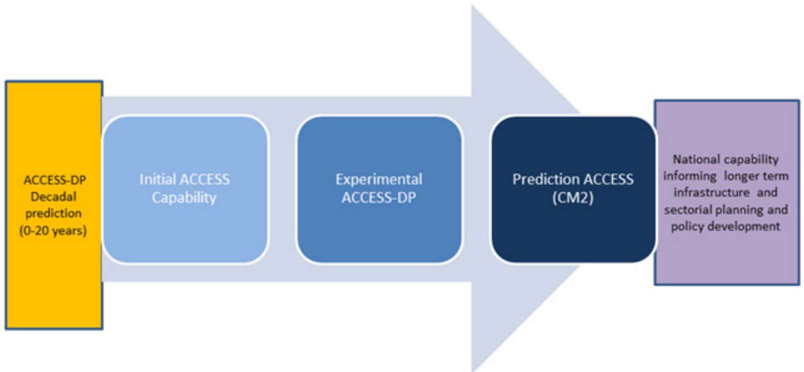

Short Term 2013-14
Medium Term 2015-16
Longer Term >2016
Outcome
ACCESS-C/D/RUC Very Short Range Weather Prediction (0-1.5 days)
Research Versions: City, on demand, RUC
PreOp FDP version with DA
Research version: Improved DA, EPS capability, precipitation
PreOp advanced DA all systems
Research :HR suite, EPS, NWP nowcast, AQ
Improved quality and more detailed information for multi hazard (including precipitation) mitigation and emergency response
ACCESS-G/R Weather Prediction (0-10 days)
Preop: APS2 suite, EPS
Research Version: Improved physics, DA, enhanced obs, application support, HIW case studies
Preop: APS2 upgrades, application support
Research version: APS3/G, DA, Extended obs, HIW case study, coupled NWP
PreOp: APS3 EPS, couple NWP, Research : APS4 extended obs, case studies, new suite plans, strategic NWP research
Improved quality, specificity and uncertainty information enhancing early warning, hazard mitigation, sectorial preparedness, and response

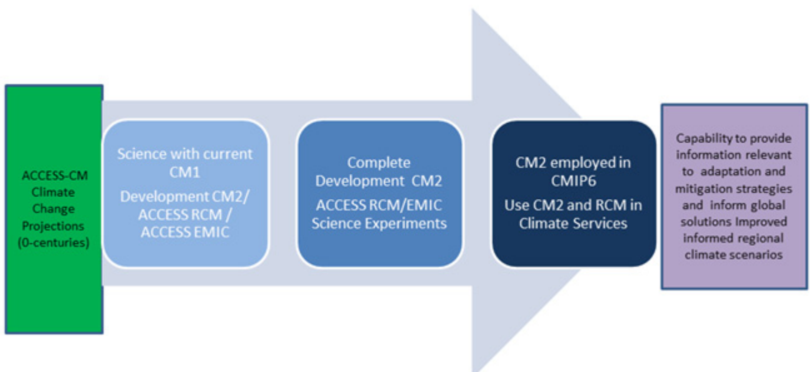

ACCESS-OM Ocean Prediction (0-10 days)
BL 10 km global resolution and ocean reanalysis
BL 10km global operational, advanced DA, diagnostics, improved surface fluxes, with waves
BL sea ice, advanced DA, BGC, reanalysis,, support coupled NWP
Increased detail and quality of information provided to offshore industry, marine defence operations, and emergency preparedness and response

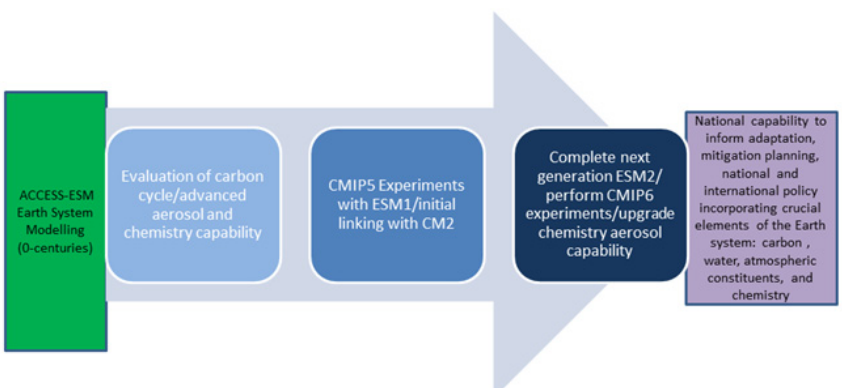

ACCESS-CO Coastal Prediction (0-10 days)
eReefs research, Tsunami and Auswave support
Operational system, DA development, adoption of primary coastal model, improved coastal wave /storm surge
Operational coastal model, Ensemble DA. Beach forecasting, storm-surge model advances
Better informed coastal sector supporting management of industry, coastal ecosystems , emergency response and risks to the environment

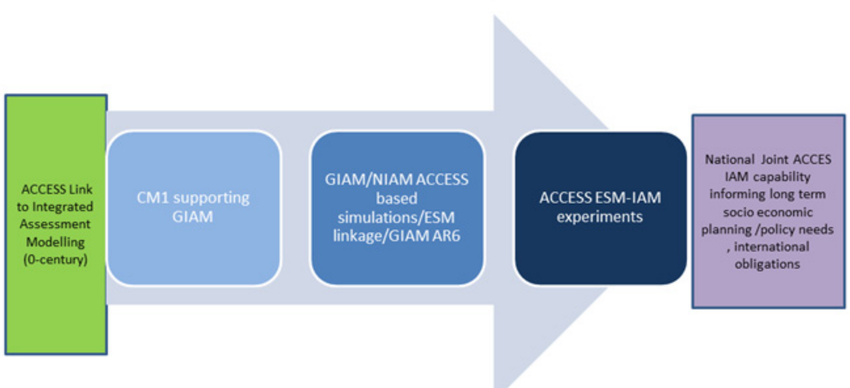

CABLE land Surface Model All time scales
Transition to CABLE2 with full carbon cycle, coupling to JULES framework
CABLE upgrades including community management and contributions , further integration with JULES
CABLE maintained as a world–class model within ACCESS incorporating carbon, nutrient, and water cycles and coupled to IAM for land cover change
Enhanced quality of weather, climate, water, carbon, environmental and ecosystem information within the ACCESS framework supporting government, industry management and policy needs


ACCESS-MW/SP Seasonal/ Multi-week/ Prediction 0-12 months
Maintain current developments
(LR)/DA initialisation
POAMA 3 PreOp , R&D ACCESS SP/MW /Physics/DA /EPS
Extensive Evaluation Model / Implement ACCESS SP/MW
Improved all year prediction of high impact weather and climate variability supporting sector specific planning ,management and emergency preparedness


ACCESS-DP Decadal prediction (0-20 years)
Initial ACCESS Capability
Experimental ACCESS-DP
Prediction ACCESS (CM2)
National capability informing longer term infrastructure and sectorial planning and policy development


ACCESS-CM Climate Change Projections (0-centuries)
Science with current CM1
Development CM2/ ACCESS RCM / ACCESS EMIC
Complete Development CM2
ACCESS RCM/EMIC Science Experiments
CM2 employed in CMIP6
Use CM2 and RCM in Climate Services
Capability to provide information relevant to adaptation and mitigation strategies and inform global solutions Improved informed regional climate scenarios


ACCESS-ESM Earth System Modelling (0-centuries)
Evaluation of carbon cycle/advanced aerosol and chemistry capability
CMIP5 Experiments with ESM1/initial linking with CM2
Complete next generation ESM2/ perform CMIP6 experiments/upgrade chemistry aerosol capability
National capability to inform adaptation, mitigation planning, national and international policy incorporating crucial elements of the Earth system: carbon , water, atmospheric constituents, and chemistry


ACCESS Link to Integrated Assessment Modelling (0-century)
CM1 supporting GIAM
GIAM/NIAM ACCESS based simulations/ESM linkage/GIAM AR6
ACCESS ESM-IAM experiments
National Joint ACCES IAM capability informing long term socio economic planning /policy needs , international obligations

Abbreviations
DA - Data Assimilation
ESM - Earth System Modelling
EPS – Ensemble Systems
IS - Information Systems
UM – Unified Model
VIZ - Visualisation Systems

RUC – Rapid Update Cycle ESM -
EnKF-Ensemble Kalman Filter
LR-Low Resolution
HR– High Resolution

APSn-ACCESS Prediction System (Weather)
CMn-ACCESS Coupled Climate Model
ESMn-ACCESS Earth system model
POAMA-Predictive Ocean Atmosphere Model for Australia
CABLE-Community Atmosphere Biosphere Land Exchange
JULES-Joint UK Land Environment Simulator
BL-BLUElink
ROAM-BL Relocatable Ocean and Atmospheric Model

IAM-Integrated Assessment Model
GIAM-Global IAM
NIAM-National IAM
EIMC-Earth System Model of Intermediate Complexity

AQ-Air Quality
BGC-Biogeochemistry
HIW-High Impact Weather
Obs-Observation
FDP-Forecast Demonstration Project

PreOp-"Pre-Operational" implies ready for hand-over to Bureau Operations.

Fig. 8 Roadmap of NG-ACCESS activities and impact on stakeholder needs

12. GOVERNANCE

To achieve the proposed delivery of a national level ESM system, effective utilisation of national capability and a process to build capacity and agreement on outputs is essential. This requires an underlying commitment of key national and international researchers, stakeholders, alignment of funding processes and agreed outcomes of common interest. It is considered that effective national governance is necessary to support the realisation of the NG-ACCESS.

Proposed principles for the governance and coordination of the NG-ACCESS framework include:

- An underlying agreement on the strategy, associated development and policy outcomes associated with ESM for the next 5 years (The Roadmap).
- The need to have NG-ACCESS and its components supported for development, evaluation and use within the community.
- A shared commitment to NG-ACCESS and an agreed set of subcomponents.
- Effective coordination of component, sub components and their integration.
- Recognition of the role played by national and international partners.
- The need to enable NG-ACCESS and its components to be exploited for operational and scientific inquiry purposes of the contributing partners.
- The ongoing need for high performance computing infrastructure and associated data and information systems.

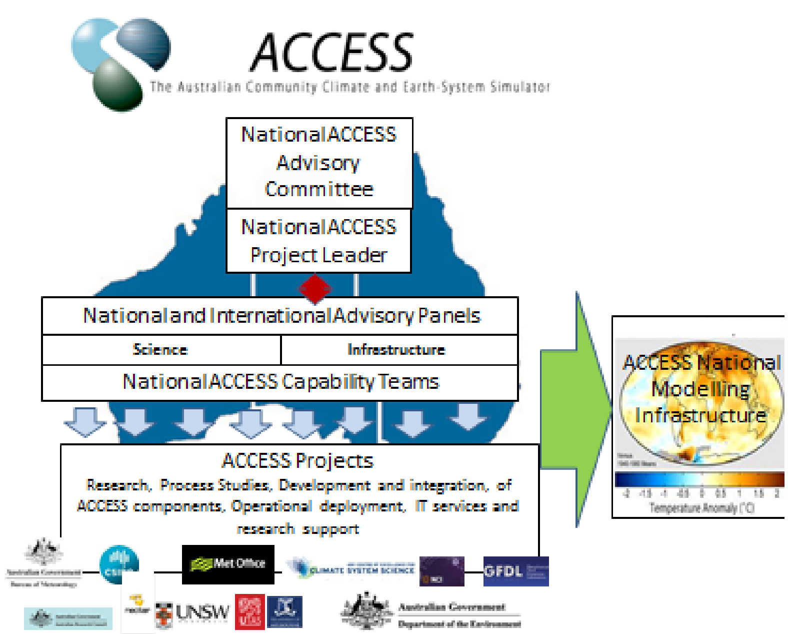


Fig. 9 Proposed governance arrangements for NG-ACCESS

Building on these principles, the governance approach should also consider licensing, custodianship of the systems, support arrangements and enabling infrastructure requirements. A NG-ACCESS consortium based on a multi-tiered nationally constituted structure is proposed to enable delivery. This approach will enhance the value proposition, increase the likelihood of multiple investments and ensure national capability is focussed on outcomes of national and international significance.

The approach is summarised in Fig. 9. A national advisory committee will provide high level strategic guidance to the primary custodians in Australia (CSIRO and the Bureau). It will be comprised of key stakeholders, primarily from supporting government agencies. Two National Advisory Panels, constituted from multiple agencies, the university sector, and with international representation will provide advice on scientific directions and technical infrastructure. A Project Leader and Deputy will be responsible for developing and implementing agreed work plans emanating from the advisory panel teams, and strategic direction setting from the National Advisory Committee. The Project Leader must be an employee of one of the two primary custodians. The Deputy Leader and members of the Science and Infrastructure panel can be employees of any of the major consortium partners.

The skills to enable the implementation will be through a series of capability teams that form the heart of the modelling and associated infrastructure expertise. This capability will be deployed to the agreed projects that will cross organisations.

Some of these activities are underway through separate CAWCR partner arrangements e.g., with the ARC CoECSS, the Met Office, NCI etc. Formalising these existing activities under an agreed set of principles supported by governance is therefore a natural step.

Some model components are both inside and outside NG-ACCESS i.e. they can operate as standalone systems such as CABLE. There is synergy in these components (with NG-ACCESS), including the need to use the same base code and have common approaches to implementation and troubleshooting. For this reason such model components are treated within the NG-ACCESS framework. The implications of such associated developments need to be considered under the joint plan that emerges through this governance structure.

13. SUMMARY

This paper has articulated a vision for the next generation of ESM capability for Australia. For a nation with increasing vulnerability and risk associated with environmental change the demands for informed decision are growing. The development of the NG-ACCESS is proposed to provide the underlying capability to address these concerns. It is recognised that the realisation of this capability cannot be met with the present approach to funding, especially if systems and solutions develop somewhat independently. To inform the complex decision making covering extensive time and space scales it is necessary to step beyond the present capability and realise a comprehensive modelling approach building on national and international intellectual capacity. Only in this way can the inter-related physical, biophysical and economic processes be represented.

To this end, building on achievements to date NG-ACCESS has been proposed. The capability delivered through NG-ACCESS will provide unprecedented changes in the type and scope of information available to the community. For the first time Australia will have a national ESM capability built specifically for and used by the Australian community. It will develop around agreed priorities and efficiently use resources. Importantly through its key partners it will have the alignment, processes and service channels necessary to deliver against key stakeholder requirements.

APPENDIX A. CASE STUDIES ILLUSTRATING THE IMPACT OF ACCESS IN DECISION MAKING

Case Study 1: Victorian floods (September 2010-February 2011)

Major event, with high societal impact: One third of the state was affected and the estimated cost of Victorian floods was $1.3 billion (Victorian Floods Review Final Report Dec 2011)

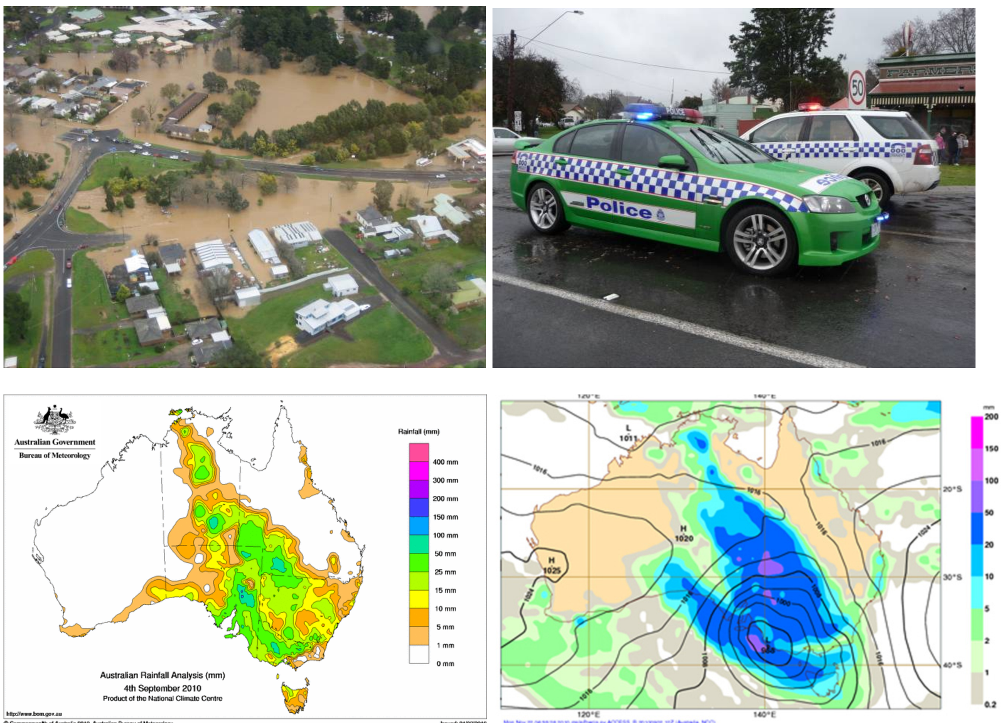


Fig. A.1 Impact of September 2010 floods on Victoria (top) and comparison of actual rainfall (bottom left) and predicted rainfall from ACCESS (bottom right) shows event well predicted five days ahead

"ACCESS once again provided excellent guidance, gave us sufficient confidence to actually predict the event not only before any substantial rain had started to fall anywhere in Australia … We could have only dreamed of this sort of performance of the NWP systems 10 or 15 years ago!"

Regional Director, Victoria

Case Study 2: Bushfires Associated with Black Saturday

The record breaking weather conditions and associated bushfires of Black Saturday 2009 caused the loss of 173 lives and in excess of $4 billion damage (2009 Victorian Royal Commission)

Fig. A.2 Bushfire event in a eucalypt forest (left) and a product depicting weather situation and associated fire danger ratings across Victoria for Black Saturday.

The Bureau provided accurate warnings of fire weather against a backdrop of a severe dry period of intense heat wave up to 7 days before the event. Existing Fire Weather Warning showing broad detail in Fire danger.

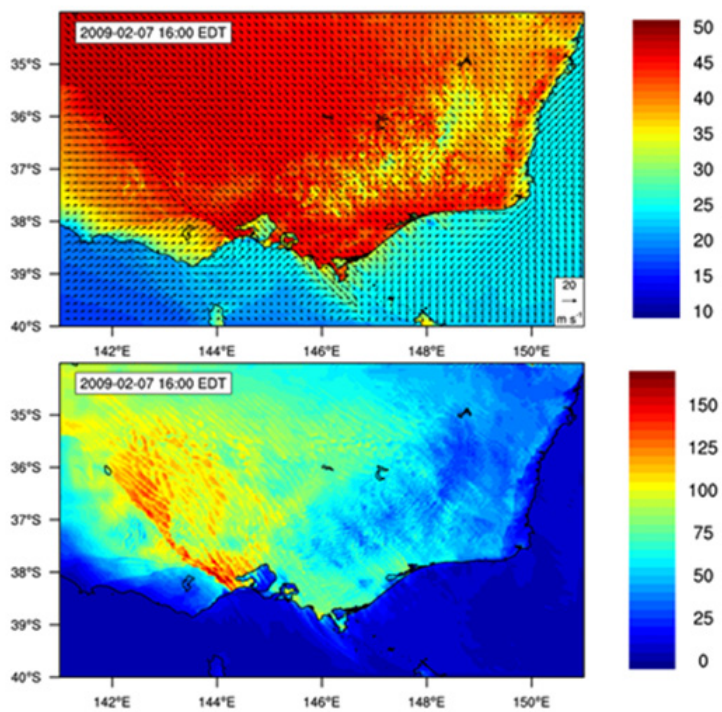


Fig. A.3 High resolution information derived from ACCESS model simulations relating to wind and temperature fields (top) and Fire Danger Rating (bottom) for Black Saturday.

Development of new ACCESS models is providing high resolution ACCESS simulations (1-2 horizontal km scale) show unprecedented spatial and temporal detail in fire weather danger supporting planning and tactical development measures in fire fighting.

Case Study 3: Impact of Seasonal Forecasts on Agricultural Decision Making

ACCESS enhancement of the Bureau seasonal prediction capability are part of the activities planned under this roadmap. Seasonal outlooks provide vital intelligence on hazards relating to floods, cyclones, bushfires and agricultural productivity.

An imperfect but skilful seasonal forecast model can put agriculture ahead. (McIntosh et al. 2012)

This study examined how POAMA seasonal outlooks can be applied to farm management in south-west WA. Significant profits can be made by varying on-farm decision based on the outlook, for example, adjusting nitrogen fertiliser inputs according to achievable grain yields allow increasing gross margins as nitrogen fertiliser costs can amount to between one quarter to one third of total input costs in wheat cropping in Australia.

Here POAMA is forecasting above/below median rainfall and the forecast is correct 19 of the 26 years studied (70% skill).

The POAMA forecast was applied to nitrogen management decision in wheat cropping. The Agricultural Production Systems SIMulator (APSIM) crop simulation model was employed to examine the impact on wheat yield. Benefits from using a forecast were calculated by altering N management using Gross Margins obtained using fixed nitrogen management relevant to above median rainfall, and those with forecasts below median rainfall. When POAMA forecast was not employed, all years were used to determine the nitrogen application.

Table A.1 Summary of potential profit margins in wheat farming related to application of Nitrogen fertiliser based on various seasonal forecasts

	Climatology (history)	Seasonal forecast (70% skill)	Perfect forecast	Seasonal forecast % of best possible
Profit	$235 000	$402 500	$490 000	66%

The above compares profit using POAMA, perfect forecasts and a climatology benchmark. With use of POAMA 66% of return on a perfect forecast is returned.

Case Study 4: ACCESS provides Climate Change Impact on rainfall, hot days and frost

Preliminary modelling for Melbourne suggests that by the middle of the twenty first century climate change may result in an annual average number of heat-related deaths five times greater than in scenarios that do not consider climate change.

The January 2009 severe heat event in Victoria demonstrated that the electricity sector is particularly vulnerable in high temperatures. It was found that during record demand for electricity (particularly in air conditioning and refrigeration), power stations were unable to increase generation. Rolling blackouts were initiated and an estimated 500,000 residents were without power at one time during the crisis. The effect of power cuts also had wider economic implications for industry, communication and ICT systems (which typically require both power and air conditioning)

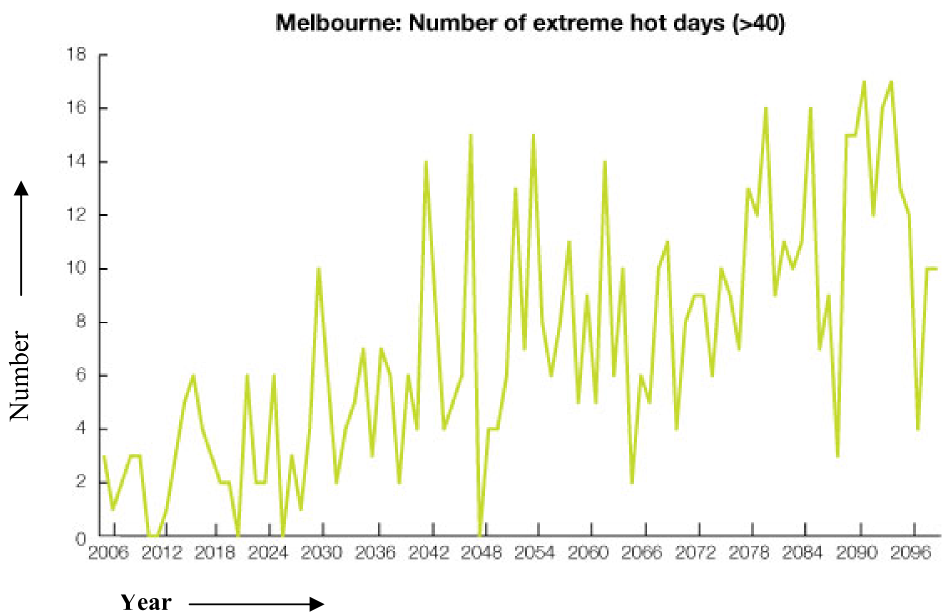


Fig. A.4 Projected number of annual hot days in Melbourne over the period 2008-2096.

FROST

Annual number of frost days in an agricultural region of Northern Victoria (i.e. days with minimum below 2°C over the model grid box) for each year from 2006 to 2100 simulated by ACCESS1.3 for RCP8.5.

A projected decrease in frost frequency and severity would reduce the risk of damage to those fruits and crops that are sensitive to frost late in the growing season, however temperate fruits that require winter chilling to ensure normal bud-burst and fruit set are at risk of lower yields and reduced fruit quality.

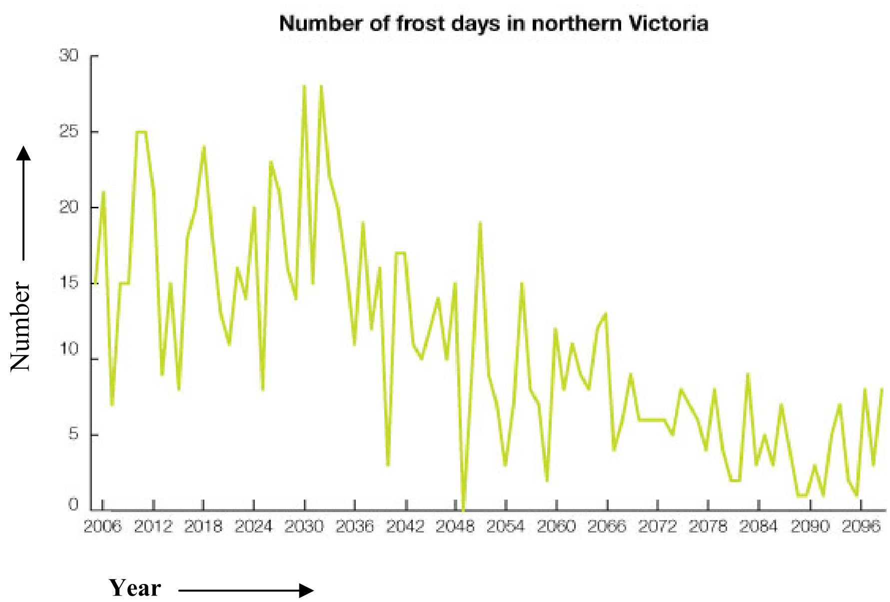


Fig. A.5 Projected number of annual frost days in northern Victoria over the period 2008-2096

The Centre for Australian Weather and Climate Research is a partnership between CSIRO and the Bureau of Meteorology.